Johnson Space Center, Houston, Texas

NASA's vision: To reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind. NASA has people working around the world – and off of it – for over 50 years, striving to answer basic questions. What's out there in space? How do we get there? What will we find? What can we learn there, or learn just by trying to get there, that will make life better here on Earth? Throughout its history, NASA has conducted or funded research that has led to numerous improvements to life here on Earth.

So what's next? With the end of the successful 30 year Shuttle program concluding with the flight of STS-135 in July of 2011, NASA JSC's leadership in space exploration continues with the management of the International Space Station, a multinational project representing the work of 16 nations, supporting permanent human presence in space. As JSC enters a new era of partnerships with commercial entities to support commercial space flight, JSC will also continue to pioneer and prove new flight technologies that improve our ability to explore; to create capabilities for sustainable human and robotic exploration; and to explore the Earth, solar system and universe beyond – charting the best route of discovery, to provide critical enabling technologies via the International Space Station and flight support, reaping the benefits of exploration in space and on Earth for society. These new technologies will also have practical applications on Earth.

Since 1961, the Johnson Space Center, located in Houston, Texas, has led NASA's efforts in human space exploration from the early Gemini, Apollo and Skylab projects to the Space Shuttle and International Space Station. In conjunction with our human space flight mission, JSC is a leader in establishing successful industry partnerships that incorporate a strong risk management and safety culture. JSC continues to pursue and develop new partnering opportunities that support national goals including energy research and technology applications. JSC is interested in improvements ranging from safety to innovative technical applications of space technology in aerospace and non-aerospace.

Examples described in this report include **Energy and Clean Environment Technologies** that currently exist, projects in work, and items of interest for the future.

1. **Multi-Platform Renewable Energy System - *An energy research success story:*** Renewable energy and education have been important themes for NASA throughout its history. Both themes are combined at the Aaron Cohen Child Care Center located at JSC in Houston, Texas, where renewable energy technologies are getting real world testing and analysis. In 2007, a Multi-Platform Renewable Energy System (MPRES) was designed and installed at this facility. The MPRES provides energy through surface-based photovoltaic arrays and wind turbines, and hot water is generated by a solar thermal panel. Data from the building can be viewed by all of JSC, other NASA facilities, and educational institutions, permitting the data accumulated to be used for both research and education. This data helps confirm the viability of renewable energy technologies and assists JSC to make cost-effective decisions for future renewable energy projects. The data is continuously collected and displayed locally and online at http://www.sacredpowercorp.com/NASA_CCC.swf.

   The MPRES provides an opportunity to better understand large, surface-based photovoltaic arrays necessary for lunar surface exploration and allows JSC to gain experience with various renewable energy technologies, to demonstrate sustainable building principles, and to assist in meeting federal energy mandates. In addition, by collocating with a facility dedicated to children, the project provides excellent educational opportunities. This project has saved critical funding with the reduction of purchased utilities and reduced JSC's green house gas footprint. In three (3) full years of operation the MPRES has generated 153,353 kWh and avoided 168,030 lbs. carbon dioxide (CO_2); 689 lbs. nitrous oxide (NOx); and 693 lbs. sulphur dioxide (SO_2). This renewable generation averted the gases emitted by 19 cars in one year and is enough power to operate 8 homes for 1 year. The MPRES provides 20% of the electrical energy needs at the Aaron Cohen Child Care Center. When the building is unoccupied during evenings and weekend and electrical load requirements are low, the surplus energy is fed to the site's electrical grid and made available to the remainder of JSC. In FY 2009 the MPRES was featured in the Federal Energy Management Program Leadership poster. This project was part of the NASA HQ Environmental Management Division's portfolio that won the 2010 Blue Marble Award for Environmental and Energy excellence in the NASA Excellence in Energy and Water Management Award – Group.

2. **Ground-based Regenerative Power Systems:** In addition to the solar arrays used at the Aaron Cohen Child Care Center, JSC is demonstrating the use of solar power in various on-site locations, including solar-powered street signs. These demonstrations are all part of an increased JSC initiative to reduce our global footprint here on earth.

3. **Energy Reduction Management:** JSC's Mission Operations Directorate has established an aggressive goal to reduce the Mission Control Center's (MCC's) IT power requirement 70% by 2015. This goal will be achieved as a result of the new MCC 21 architecture that leverages commercial-off-the-shelf (COTS) hardware and software which replaces old, expensive to operate legacy systems, as well as the new MCC voice system. As a result of the new MCC architecture and voice system, operations, maintenance, and development costs will be significantly reduced for all programs MOD supports and will open the network to new commercial customers.

4. **Fuel Cell Technology:** A fuel cell is an electrochemical device that can produce electricity from a reaction between hydrogen (fuel) and oxygen (oxidant). Unlike a battery, a fuel cell operates as long as fuel and oxidant are supplied. The by-product is water which can be used for human consumption, vehicle cooling, or other purposes. NASA has developed fuel cell system designs, components, and power control technologies for its space exploration efforts that could be beneficial when applied to terrestrial fuel cell power systems.

   In collaboration with the NASA JSC Energy Systems Division and NASA Glenn Research Center, research and development of high performance proton exchange membrane fuel cells (PEMFC) has matured. Future collaborations with the Department of Energy and the Department of the Navy look to apply PEMFC technology and further develop Solid Oxide Fuel Cells (SOFC) using green propellants (methane and oxygen). Clean and quiet, the fuel cell is ideal for environmentally sensitive applications including electric cars, buses, hospital power supplies, and residential and utility power generation. In addition, nanomaterials are enabling advanced fuel cells. These fuel cells can be coupled with hydrogen to generate electrical power.

5. **Green Energy Technology:** NASA JSC is actively engaged in the demonstration of an integrated spacecraft fluid and thermal system that minimizes dry mass, reduces complexity of system design, and reduces the number of different fluids used on the spacecraft. Liquid oxygen/liquid methane (LOX/CH4) has been selected as a high performance green propellant with potential applicability for multiple emerging NASA missions as it is clean burning, storable in space and supports applications for propulsion, power reactants, life support system breathing gas and heat rejection. In addition to the benefits already listed, this technology enables lean development through safer and more efficient testing as compared to toxic propellants, and significant reduction in ground test cost verses storable hypergolic propellants. LOX/CH4, combined with SOFC technology, may have applicability to terrestrial and marine applications.

6. **Battery Technologies:** NASA JSC utilizes a combination of power generation and energy storage components for all manned and unmanned vehicles. JSC is actively engaged in the research and development, improvement and demonstration of various Lithium-based cell chemistries. Energy storage, energy density, cycle life and safety are all important criteria in the selection and usage of batteries. JSC strives to utilize batteries with the highest energy density and is constantly trying to improve upon that parameter without jeopardizing safety. JSC is also pursuing the screening of potentially hazardous Li-ion cells to assure their safety prior to use. Both improved energy density and increased battery safety are applicable to earth-based applications, especially with ever-advancing electronics and the need to increase regenerative energy sources.

7. **Solar Power Satellites Technology:** As NASA JSC continues to develop spacecraft and explore space, the use of solar arrays for power generation of vehicles and satellites will continue. Solar arrays are currently used on the International Space Station for regenerative power, where they initially generated >1MW of power, and they have been utilized extensively on numerous other satellite power systems. Solar power is undoubtedly another important constituent of a regenerative power system in conjunction with either batteries or fuel cells for satellites, interplanetary exploration, and earth-based applications.

8. **Microwave Power Transmission and Photonics:** Space-based solar power is considered to be the collection of energy in space from the sun and its wireless transmission from space to earth. Such a system can offer secure energy, environmental, and technological advantages to this nation and its users. Space-based solar power offers one possible solution to energy independence for our country. It can certainly be an integral part of alternative energy solutions. NASA JSC has **proposed** a series of ground and flight experiments to demonstrate the safe and positive control of a wireless power transmission microwave beam from space to ground. These experiments would eventually demonstrate sufficient wireless power transmission to validate the operational utility of this concept.

At the present time two engineering technologies are being developed in-house at JSC that are required for wireless power transmission: (1) the development of a retrodirective phase control system for electronically steering the microwave beam to a very precise location on the earth, thereby not allowing any beam "wander", and (2) the development of a photonics (laser) system for distributing a microwave phase reference throughout a large phased array antenna for transmitting the microwave power beam. This photonics system uses a unique feedback technology for stabilizing the microwave phase reference being distributed throughout a large antenna.

These two technologies have other applications such as: (1) use of a precise controlled microwave beam for point-to-point power transmission, (2) use in radio astronomy where a precisely stabilized phasing signal must be distributed to widely separated antennas, and (3) electrical propulsion to space vehicles. There are several potential end-users (customers) with different system requirements, i.e., the commercial sector and military. For these users, the primary power generation method will probably be either photovoltaic or solar thermal power. This direct current (DC) power would be converted to microwave power through the use of high efficiency traveling-wave tube amplifiers (TWTA) operating at a high microwave frequency. This microwave energy would then be transmitted to earth using a high gain phased array antenna in space. This microwave energy would be received on the earth and converted back to DC energy for utilization by the customer.

9. **Hydrogen or Methane Storage:** New nanomaterials are enabling dense storage of fuels for transportation. Currently hydrogen has to be cooled to 77^{o}K while methane storage systems are capable of room temperature operation. One option for storing hydrogen is metal organic frameworks which act as a cage to constrain the hydrogen molecules. The Department of Energy has interest in this technology and is funding fuel storage projects. NASA has interest in this technology because it can be used to solve the radiation problem for deep space missions – fuel stored in habitats walls would provide radiation protection.

10. **Steam Methane Reformation:** Nanocatalysts could be used to improve efficiencies in the steam methane reformation process. Given that this is the primary method of generating hydrogen, industry would have interest if improved efficiencies could be realized. This process coupled with natural gas could significantly reduce green house gas production in the United States if the appropriate system could be developed separating out the byproduct CO2 and then storing the gas for use in the chemical industry. Nanomaterials could be used to separate the gas enabling a compact environmentally friendly system. NASA has interest in harvesting methane from planets and converting the methane to hydrogen for propulsion and use with fuel cells.

11. **Air Purification Technology:** JSC researchers continue to investigate better ways to remove carbon dioxide (CO_2) and toxic gases from spacecraft atmospheres. Removal of combustion products with gold nano-materials, air purification with silica-titania composites and amines to remove CO_2 are some examples. These and other technologies for aerospace life support systems also have many applications for removing toxic chemicals or reducing unwanted CO_2 on Earth.

12. **Water Purification Technology:** JSC is advancing technology for recycling spacecraft wastewater using bio-reactors for wastewater treatment. The overall system approach includes a bio-reactor primary processor, compatible "green" disinfection and unique membrane-based salt removal. There are many parallels with terrestrial wastewater treatment, which could lead to advances in low-energy wastewater treatment and water reuse in a world where clean water is becoming scarcer.

13. **Membrane based water purification systems:** Methods of reducing fouling in membrane water filtration systems are under development to make spacecraft water recycling systems last longer and use less energy. Forward osmosis, rotating reverse osmosis and direct osmotic concentration are some technologies which have been investigated. This field of research has excellent spin-off potential for improved treatment of wastewater on Earth and space.

14. **Post-processing systems for water purification:** NASA is developing technologies for water disinfection via water post-processing systems that ensure water recovered in closed-loop water recovery systems is safe for long-term human consumption by removal of residual contaminants. Technologies to polish processed water to potable quality for direct re-use by the astronauts include development of thermal-catalytic, photolytic, and vapor phase catalytic technologies for near-term application and evaluation of advanced photo-catalytic oxidation technologies for future application as post-processor treatment systems. Many of these, such as ultra-violet photo-catalysis, have excellent potential for use on Earth as new light emitting diode technologies emerge.

15. **Water Purification Technology:** Addressing bacterial contamination of water systems in space and on exploration missions is a high priority for NASA. Water systems are vulnerable to bacterial contamination, which can be harmful to human health. Areas of focus for water decontamination include: prevention of bacterial growth and biofilm formation in water systems, internal cooling loops and heat exchange systems. Currently, bacteria thriving in water systems are treated using iodine which produces undesirable health effects. Nonchemical alternatives are urgently needed. Our research has demonstrated that microwave energy effectively kills bacteria in water without the need for chemicals or additives (i.e. iodine). In laboratory tests using a model water circulation unit, specific microwave frequencies were used to eradicate a common water contaminant aboard the International Space Station called Burkholderia Capacia. A single exposure killed 100% of biofilm bacteria and 94% of the water born bacteria. This simple but effective system would be widely applicable on Earth to purify water systems world-wide and could be useful in countries currently lacking the means to implement more traditional, costly water purification systems.

16. **Surface Decontamination:** On the International Space Station and for future Exploration missions, the habitat must be routinely and thoroughly cleansed. In space, however, ubiquitous microorganisms can become more virulent and resistant to conventional disinfection procedures. To address this issue, a light- weight, portable hand held microwave wand is under development that utilizes specific radiofrequencies to effectively kill microbes in the environment (surfaces and difficult access areas). This technology can be used for housekeeping functions and would reduce the need for cleansers to sterilize the environment thereby increasing efficiency and minimizing up mass. Once fully developed, this technology will advance current sterilization methods and could be widely applicable on Earth; i.e., commercial sector (doctor's offices, hospitals, homes, laboratories, veterinary medicine, military, etc). It will be particularly useful for surface decontamination when using chemicals is neither desired nor feasible.

17. **Bio or Recycled Fuel:** Currently waste on spacecraft is disposed of, but as we go farther into space, we must reuse and recycle even more. Research is underway to make propellants or other fuels from trash using techniques such as pyrolysis, incineration and gasification, to name a few. These same technologies are becoming more important on Earth as we strive to reduce the growing burden on landfills and the emission of greenhouse gases from them.

18. **Environmentally Friendly Fluids:** Since a single thermal control fluid loop inside and outside the spacecraft would help reduce mass and power, JSC is developing technologies that will allow this, including non-toxic thermal control fluids – single phase heat transfer fluids and refrigerants. New techniques for containing non-toxic phase change materials are also under development. Results from these phase change material tests and chemical analyses of fluids may one day lead to new products that improve life on Earth.

19. **Solar powered heat pumps for heating and cooling:** Research and development is being conducted at JSC on high efficiency refrigeration systems, or "heat pumps", that can be used to provide heating, cooling or both. Past efforts focused on the interface and controls required to directly power heat pumps from solar panels and several patents were received for a battery-free solar refrigeration system. Current efforts are focused on providing simultaneous heating and cooling of water at opposite ends of the heat pump to provide a drastic reduction in energy use in a potable water dispenser that will provide hot and cold water for astronaut meals. Many applications on Earth can benefit from these advances, such as home and industrial water heaters, refrigerators and air-conditioners.

20. **New Energy Technologies:** JSC has patented a proven, solar-powered refrigeration system that eliminates reliance on an electric grid, requires no batteries, and stores thermal energy for efficient use when sunlight is absent. The innovation uses a variable speed, direct current (DC) vapor compression cooling system, connected to a solar photovoltaic (PV) panel via novel electronic controls. This environmentally friendly system is ideal for use in commercial or household refrigerators, freezers, vaccine coolers, or solar ice-makers. It is particularly ideal for off-grid applications.

21. **Battery Management System:** JSC developed a battery management system that features the ability to monitor and balance the charge of individual battery cells that are in series and provide fault detection of individual cells in parallel within a battery pack of hundreds of cells. The circuit uses fewer connections (pins) than competing technologies, which reduces complexity and improves reliability. It offers a safe and potentially low-cost management system for high-voltage battery systems, including lithium-ion (Li-ion) battery systems that are used in electric vehicles and other next-generation renewable energy applications.

22. **Parasitic Power Control in Fuel Cell Systems:** JSC developed a method for efficiently controlling parasitic power in fuel cell systems. "Parasitic power" refers to power required for internal system maintenance rather than for the system's primary purpose of net power output. Originally designed for spacecraft, this novel method employs a single self-regulating control signal that does away with overly complex control strategies and external power controllers, such as electronic power control units, sensors, and thermostatic controllers. In situations where efficiency and reliability are crucial, this innovative method simplifies and reduces operating costs for fuel cell power systems.

23. **Self-regulated Water Separator:** JSC has patented a technology that provides centrifugal separation of fuel cell product water from oxidant gas. The innovation uses the flow energy of the fuel cell's two-phase water and oxidant flow stream, rather than actively controlled electric motors, to augment separation efficiency. Unlike some product water removal systems, the JSC technology does not depend on hydrophobic or hydrophilic surfaces, which are subject to fouling and gradual deterioration in performance. By eliminating the need for specialized surfaces, active control systems, and motor-driven components, the innovators have developed a separator that is simpler and more reliable than similar systems.

24. **Petroleum deposit survey and evaluation:** JSC has patented a system for surveying and evaluating space-based images to locate geographic areas favorable for petroleum deposits. The technology identifies accumulations of sediments arranged in fluvial fan patterns that may be indicative of deposits of petroleum and other minerals. The fans can spread out to radii of 100 kilometers or more and are barely recognizable from the ground or low-altitude photographs because of their scale and gentle slopes. International Space Station photographs, supported by 1:1,000,000 maps, reveal basinal geological settings with relatively young sediments and distributary drainage. A process that can reliably narrow the search for petroleum deposits could result in tremendous savings for the petroleum industry.

25. **Improved ground penetrating radar system for detecting subterranean interfaces:** JSC developed technology uses relatively lower frequencies, which results in better penetration of media and higher resolution. One main application of the technology is its use in detecting interfaces such as the movement of approaching water in oil producing wells. While the invention is mainly discussed in terms of use within a borehole, the invention is highly adaptable and may be used for other purposes such as geological mapping and the location of objects that are buried deep within the ocean floor.

For More Information Please Contact:
Strategic Opportunities and Partnership Development Office
Phone Number: 281.483.3000
E-mail: JSC-Partnerships@mail.nasa.gov